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Title: Laser-Driven Counter-Propagating Shear Experiments

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Intended for: Presentation

Laser-Driven Counter-propagating Shear Experiments

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J. Kline, E. Loomis, K. Flippo

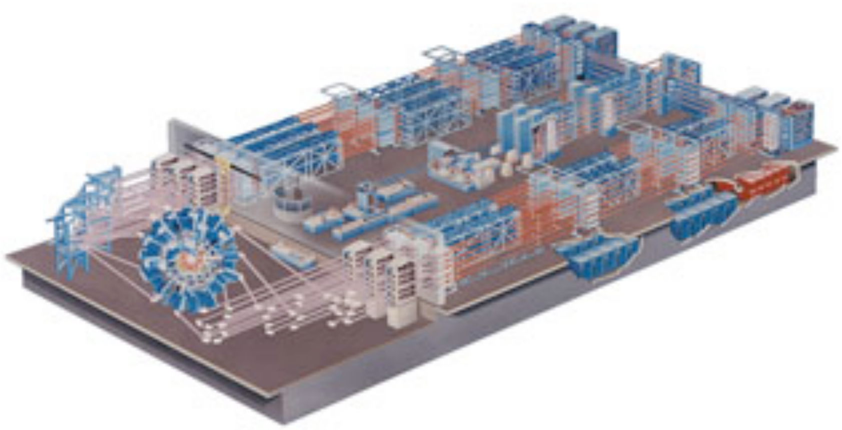
This talk will include:

- **Experiment overview**
- **Radiographs and data extraction (edge on)**
- **Modeling (simulation)**
- **Radiographs (orthogonal direction)**
- **Modeling (theory)**

F W Doss et al *Phys. Plasmas* **20**, 012707 (2013)

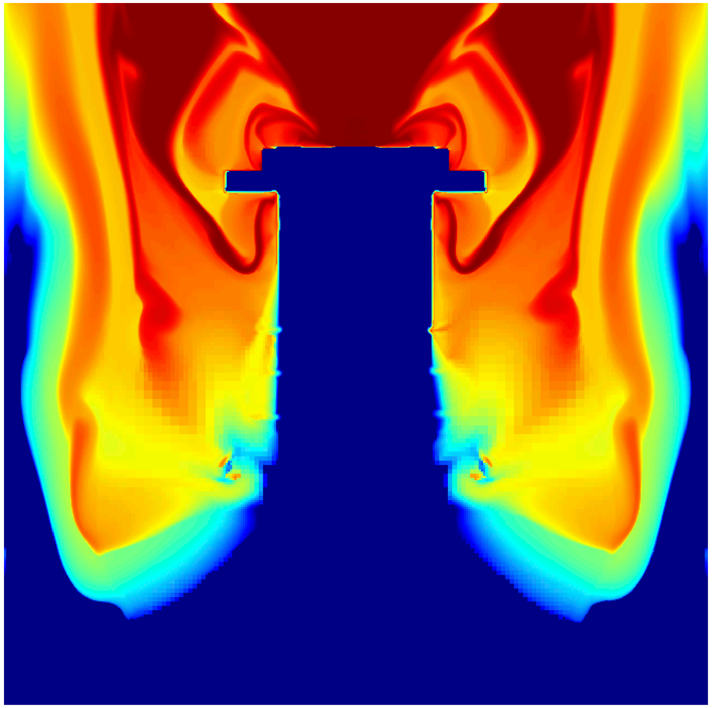
The reshock & shear campaigns investigate compressible, variable density mixing

- **Experimentally investigate mixing physics in high-energy-density regimes.**
- **Provide validation data for LANL's BHR turbulence model.**
- **Experiments conducted at LLE's Omega laser facility.**



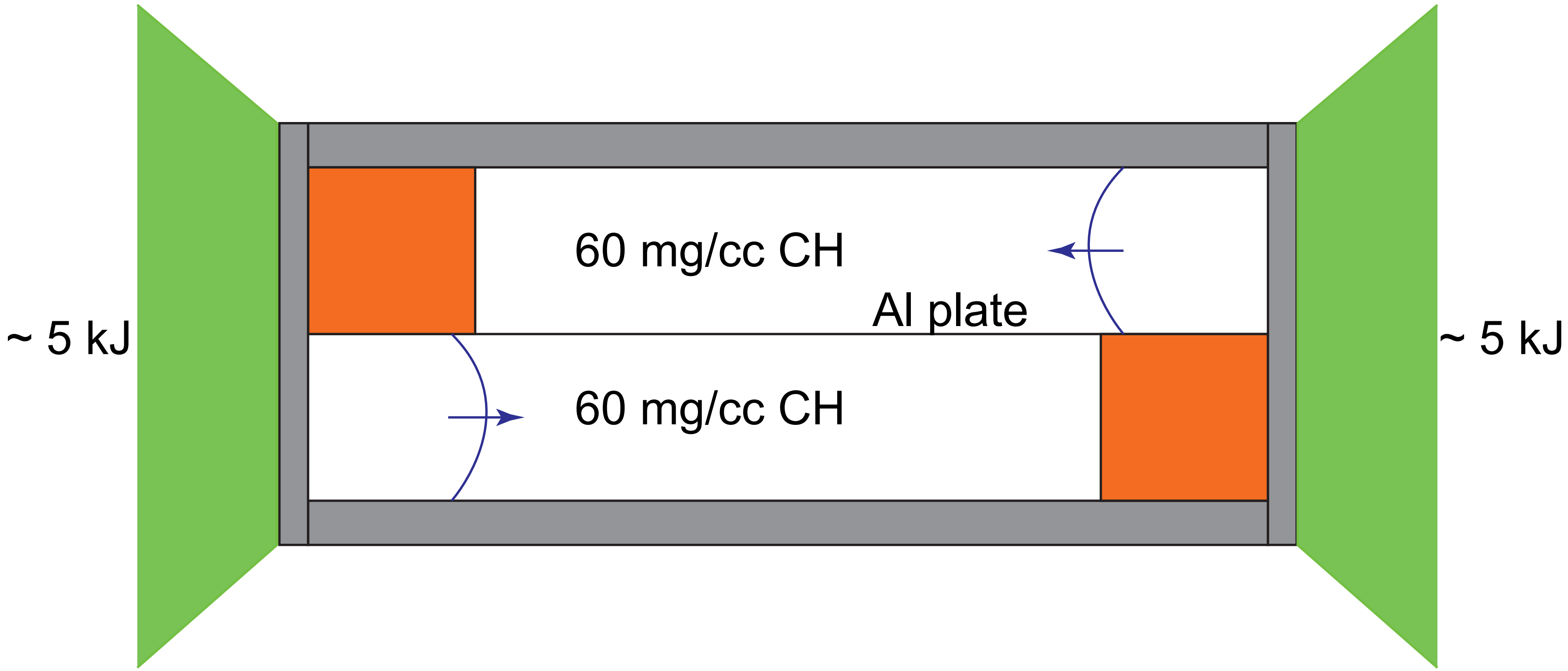
Experiment parameters

- This experiment achieves Re ~ 4*10^5 (delta-delta-dot definition) / 3*10^6 (Delta-V definition)
- Zhou's transition time (delta-delta-dot) ~ 10 ns.
- Mach number 2 flow on each side. (70 km/sec, 10 - 20 eV material)
- Shear rate ~ 3 ns^{-1} (GHz).
- Post-shock density ratio > 5.



- Compressibility and variable density effects are important here.

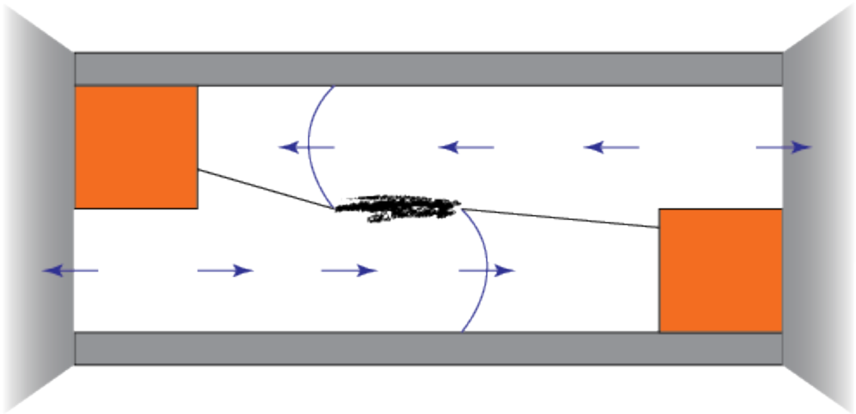
Counter-propagating shear experiment



- The main idea: Dense plugs block half of each side's drive.

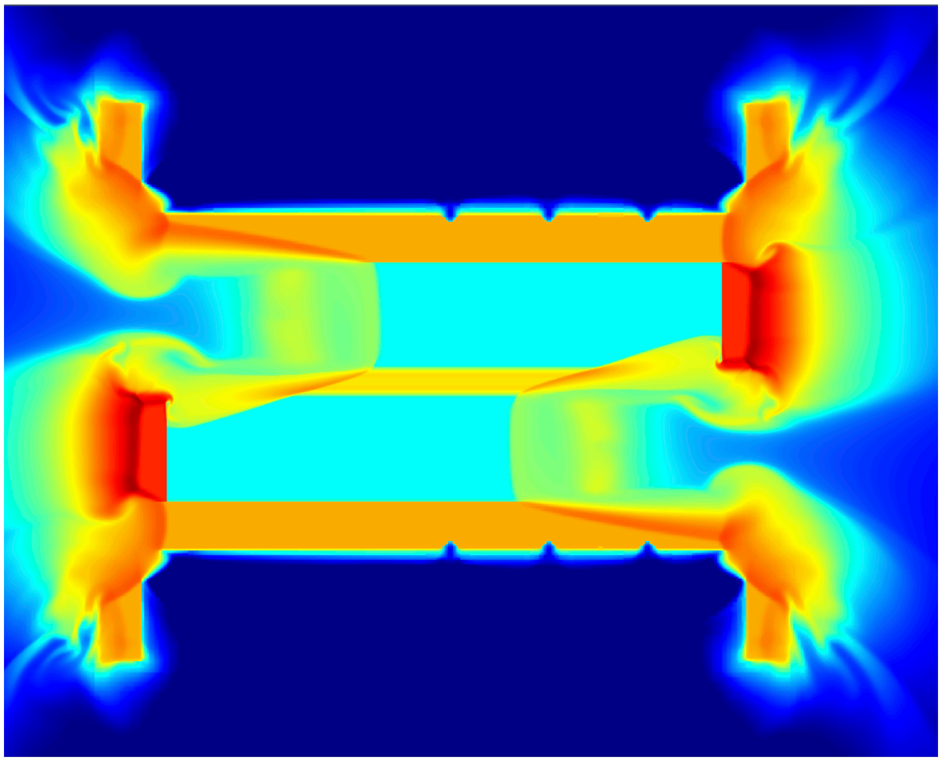
Features of the counter-propagating geometry

- Higher shear (~ 70 km/sec on each side = ~ 140 km/sec net difference).
- Higher convective Mach number (2).
- **Symmetry**: pressure is balanced between two sides, so no net motion or expansion of the layer due to pressure gradients.
- After the initial wave transients die down, past a certain point *any growth of the layer is due only to the shear instability*.

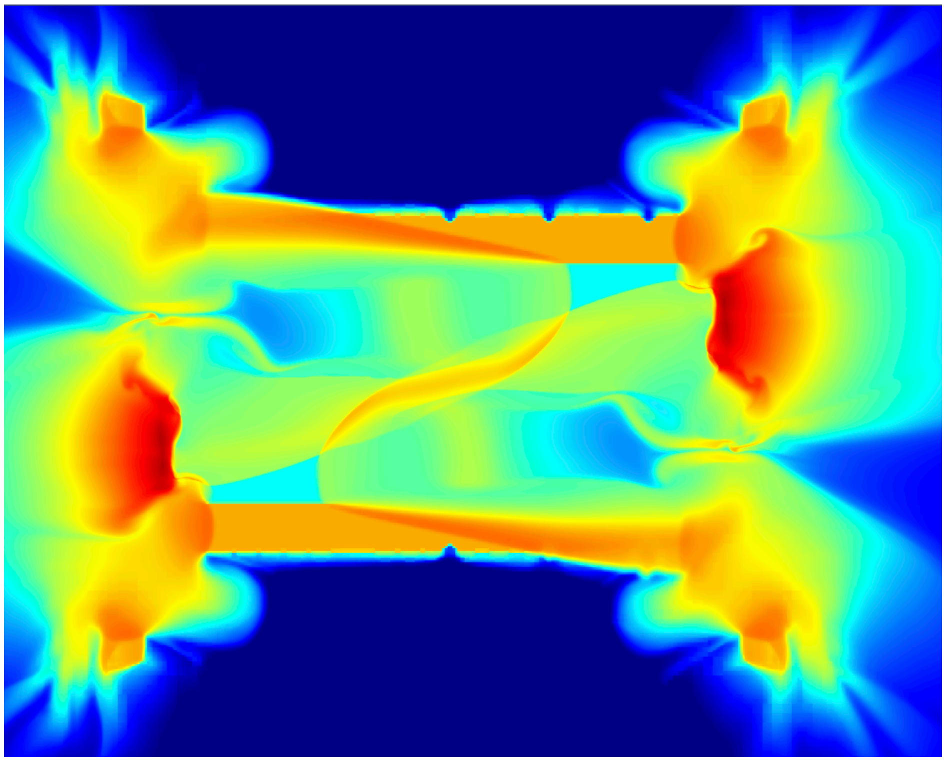


Simulations ran in the RAGE hydrocode

4 ns

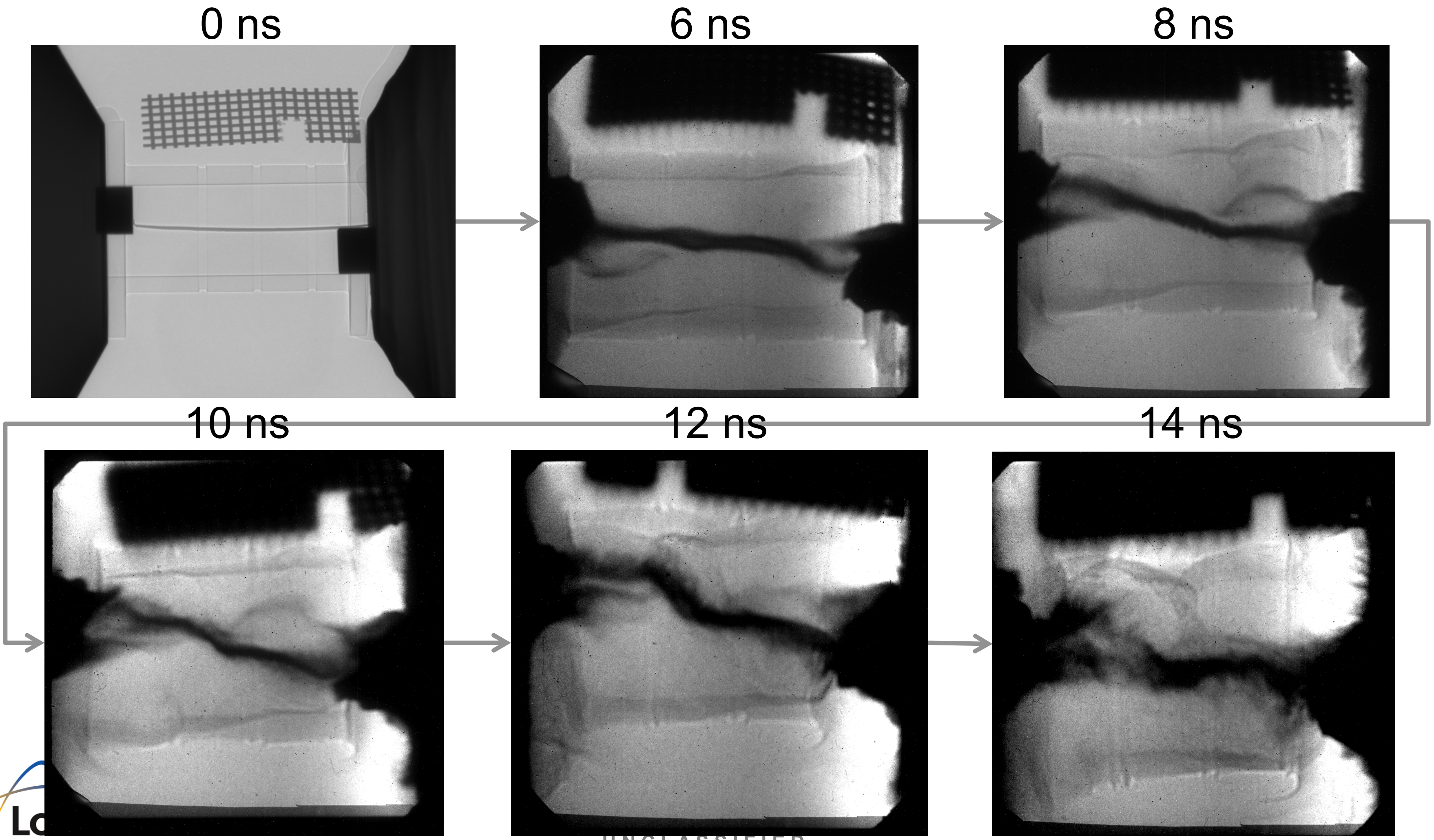


10 ns

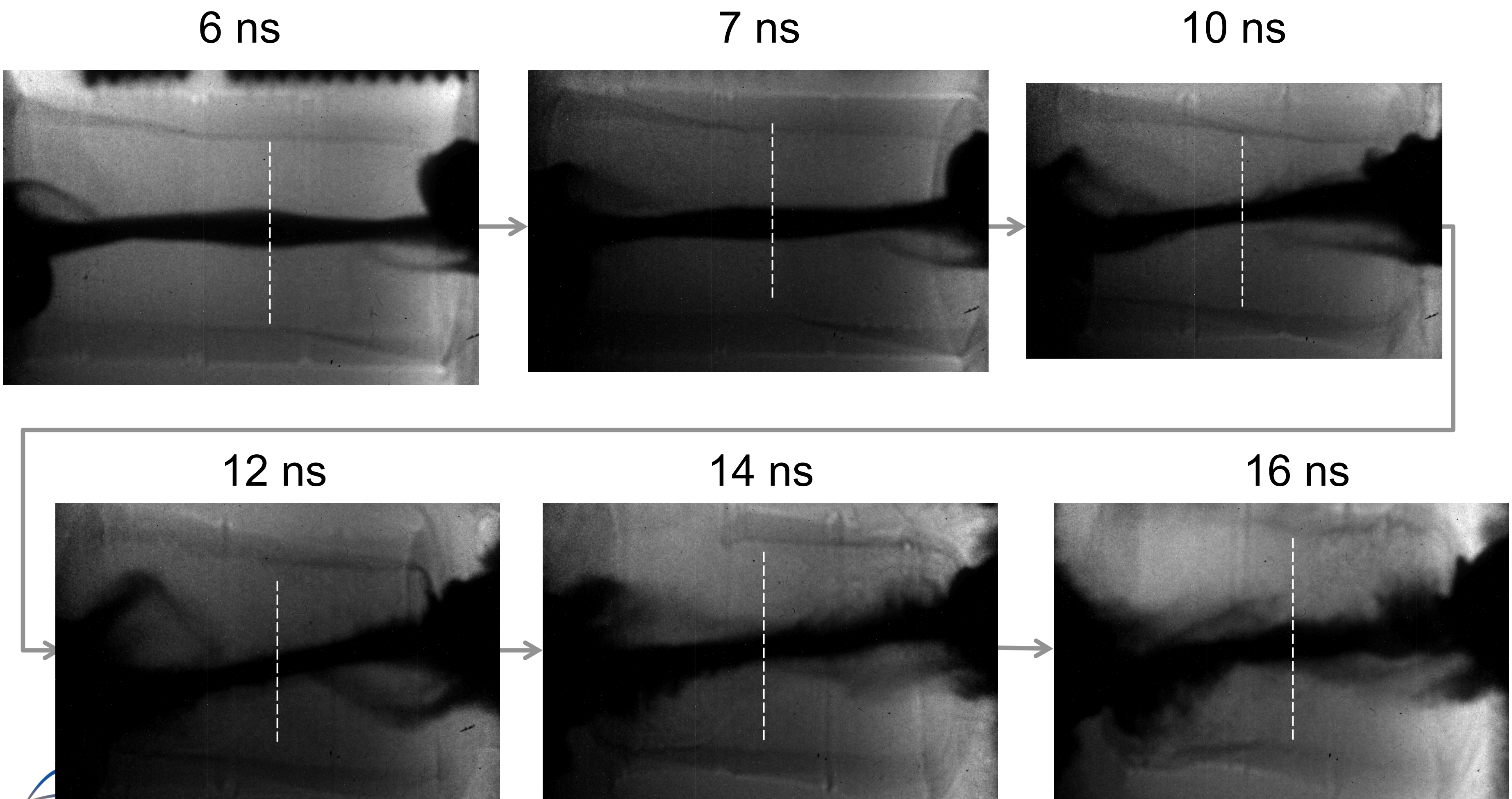


- **Mix widths were extracted from the simulations using the same metric as the experimental radiographs.**

Radiographs are taken edge-on and orthogonal (March 2012 campaign)

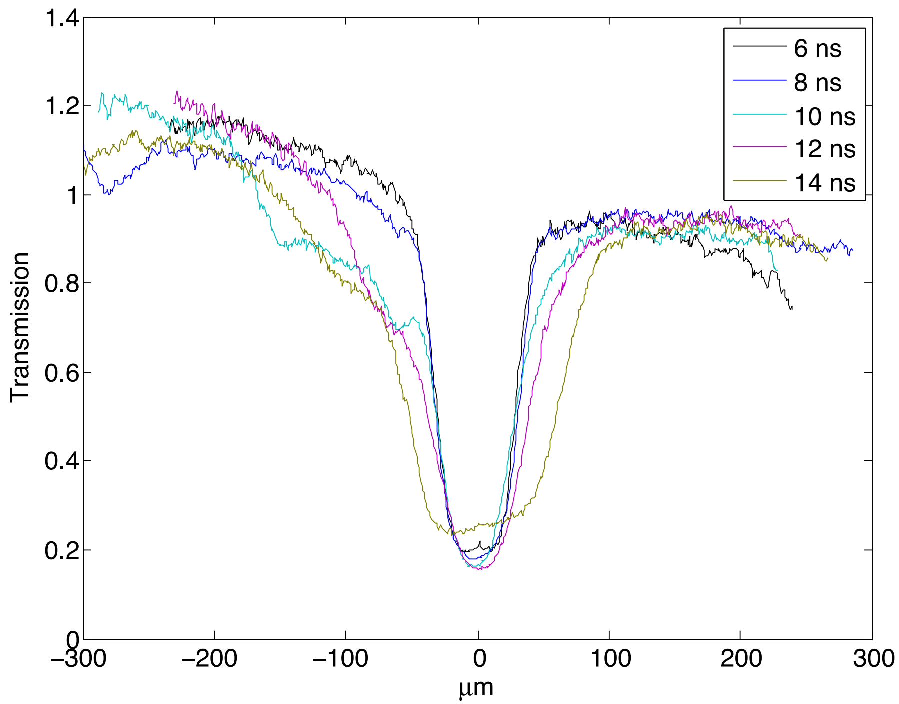


Lineouts are taken from radiographs at observed shock crossing location (July 2012 Campaign)

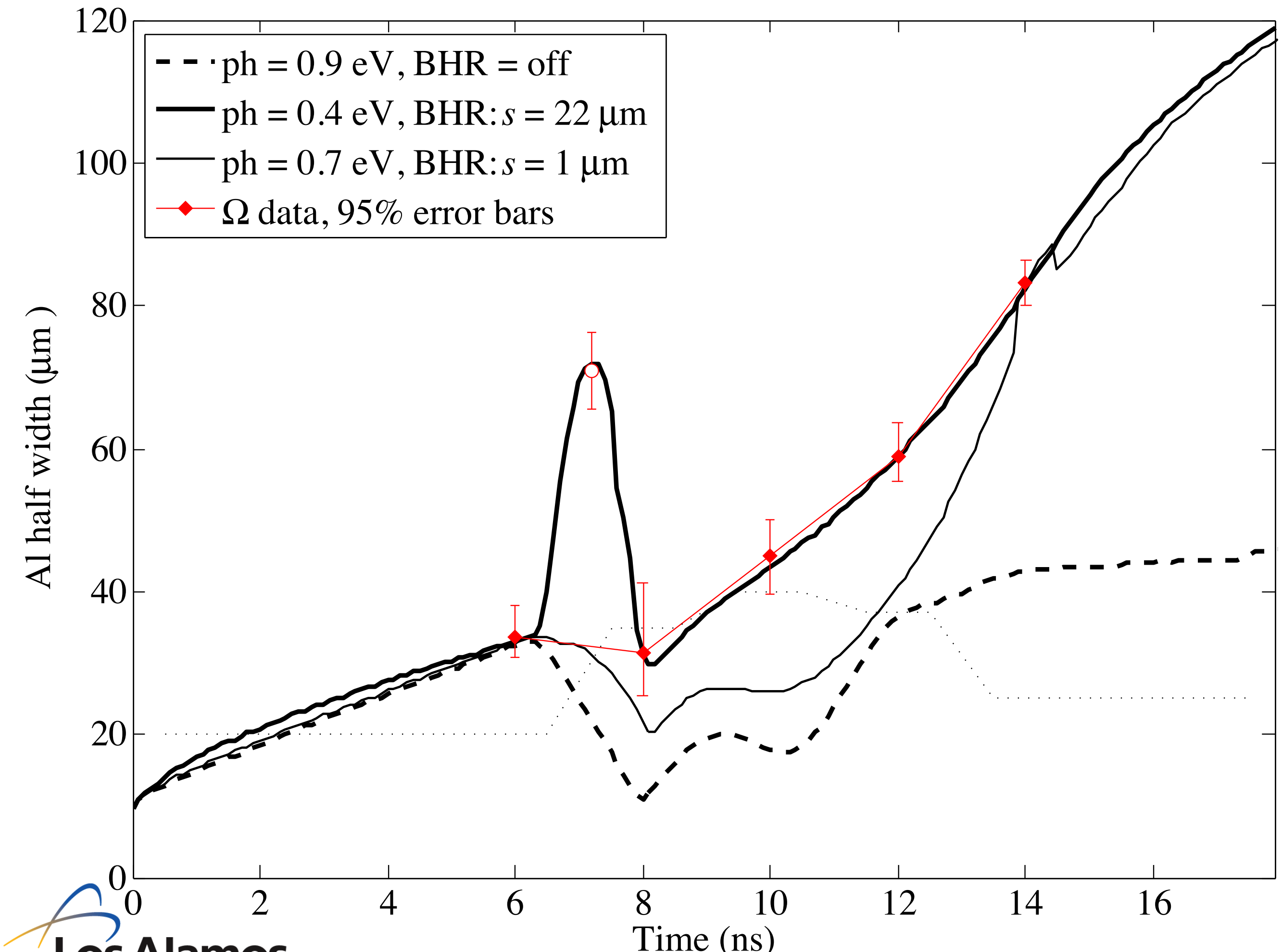


Lineouts extracted from radiographs give Al layer width

- 4.3 keV Sc line well absorbed by the Al layer.
- Everything else in the system is pretty much transparent.
- Lineout taken across tube center.



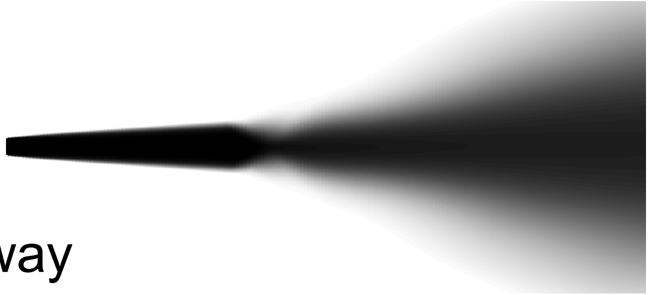
Simulations with and without turbulence



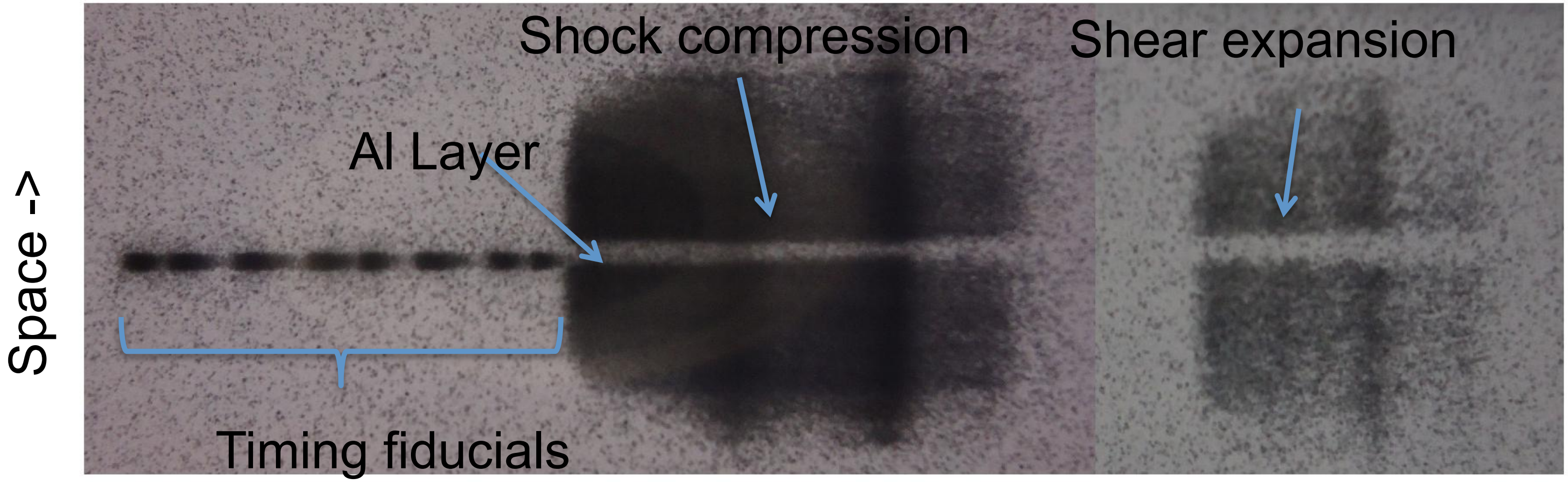
- **RAGE clean calculations miss the data.**
- **RAGE with BHR can reproduce the data, using a length scale parameter comparable to layer thickness, rather than layer roughness.**
- **Preheat selected to match 6 ns point.**
- **Dust-up appears in the simulation for long enough length scales *s*.**
- ***s* from 20s to low 30s can match all mix widths except the dust-up point.**
- **After 14 ns, conditions are very insensitive to the initial BHR parameters (but sensitive to having BHR on).**

Current work on implementing streak radiography (November 2012 Campaign)

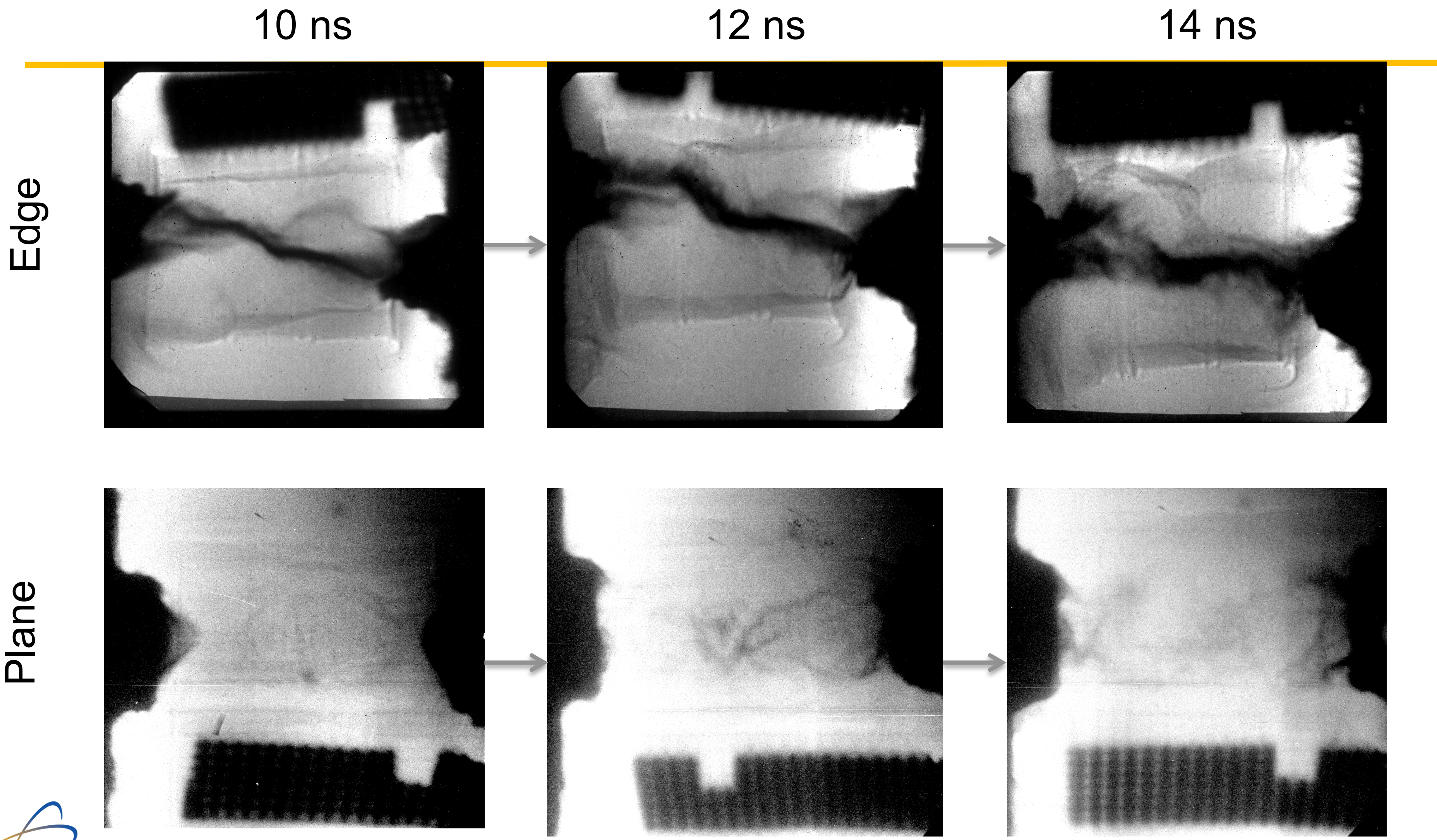
- Streak radiography can capture more time evolution per shot, but loses information off the centerline.
- Simulated streak (whole experiment)



- Data (two shots),
  interpretation and comparison underway

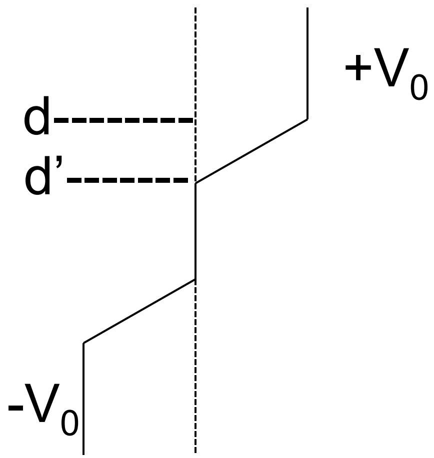


Data in the other direction sees nonlinear structures, observes transition to turbulence



The visible striations at 10 ns compare to a most unstable mode in linear stability analysis

- The equations are moderately unpleasant.
- In the limit of d'->0, recover the "vortex stratum" solved by Lord Rayleigh in *The Theory of Sound*. (Only three terms survive.)



- In the further limit of d ->0, get classic Kelvin-Helmholtz. (One term survives.)
- Most unstable wavelength is around 2π(d-d').

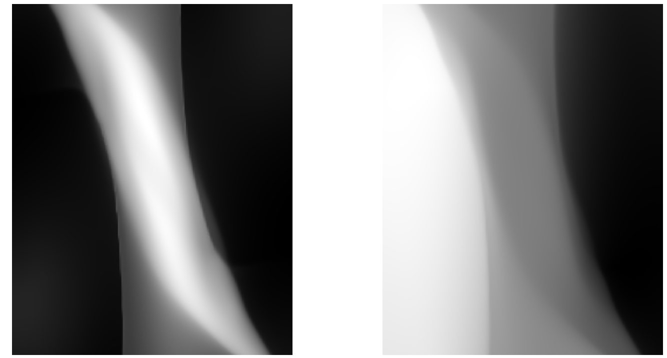
$$\left(\frac{n^2 d^2}{V_0^2}\right)^2 - \frac{n^2 d^2}{V_0^2} D + Y^2 \operatorname{csch}(2kd)\sinh 2kd' = 0$$

$$D = \frac{5}{4a^2} + (kd)^2 - \frac{2kd}{a}\coth(2kd) - \frac{3}{2a^2}\frac{\sinh 2kd'}{\sinh 2kd} - \frac{1}{4a^2}\frac{\sinh 2k(d-d')}{\sinh 2kd}$$

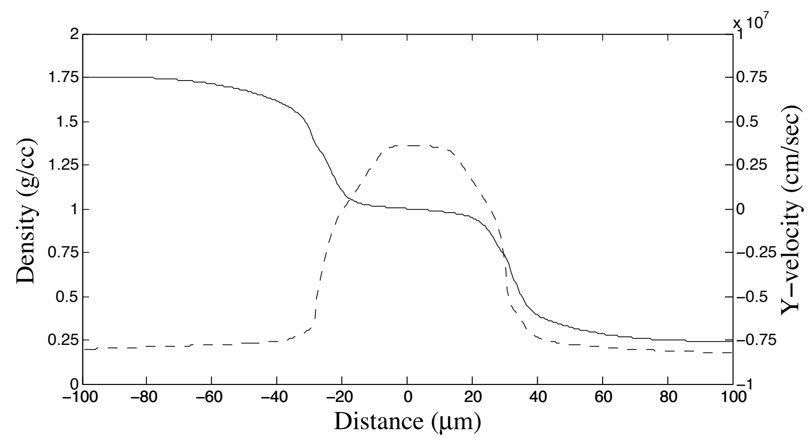
$$d' = (1-a)d, \quad Y = \frac{1}{a^2}(akd\cosh akd - \sinh akd)$$

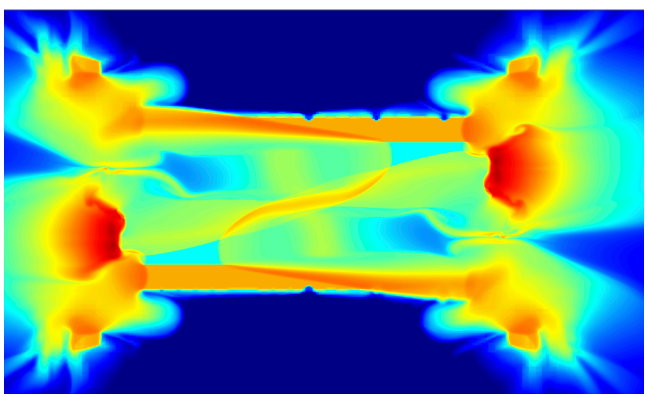
Using values from simulation in linear theory, predicts most unstable wavelength

- Using values from the simulation at 8 ns into the linear theory predicts a most unstable wavelength of 55 microns.
- Data from FT transform of orthogonal view = 57 +- 7 microns.



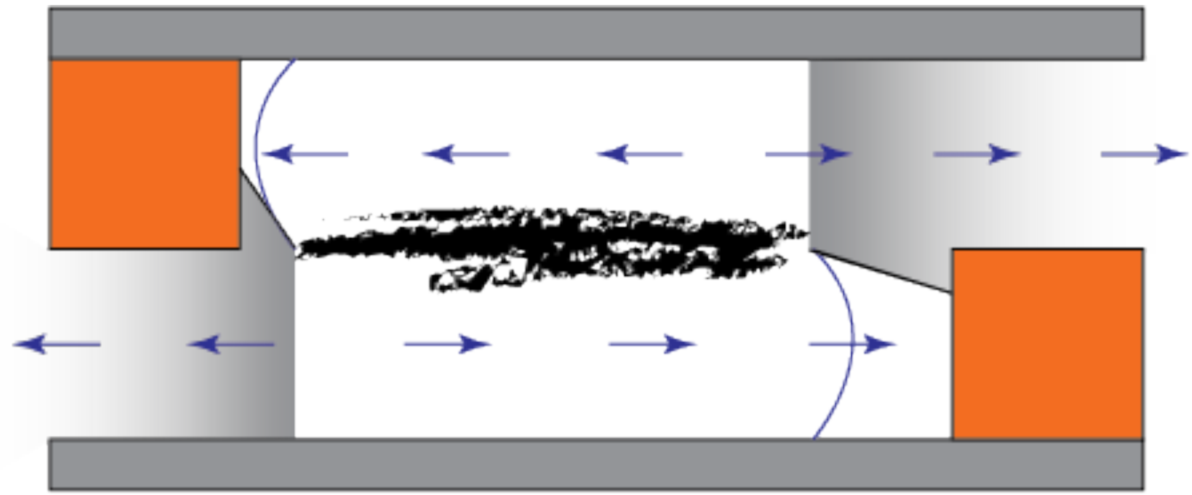
Density Y−velocity





Limits imposed by geometry and drive

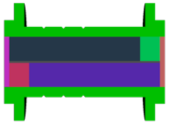
- The counter-propagating geometry takes half a shock transit time to create the pure shear region, which then persists for one shock transit time, at which point the shock has bounced back to the center.
- In the Omega experiments, 7 ns to create shear region, and at 18+ ns the reflections terminate the experiment.
- Radial edge effects are becoming noticeable at similar times.



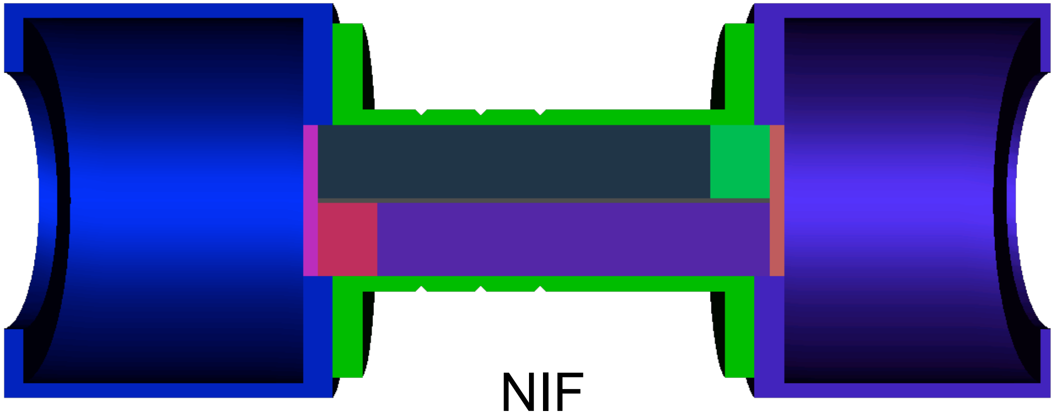
NIF scaled experiment

- **These issues are addressed by a NIF sized variant of the experiment:**
  - Enormous target volume moves edge effects and experiment-ending reflections further away in time from affecting the shear centerline.
  - Long pulse indirectly drive from halfraums to support the shocks, stave off rarefactions.
  - Streak radiography to collect time history with fewer shots.
  - The NIF scaled experiment will push well past the transition regime.

To scale target designs:



Omega



NIF

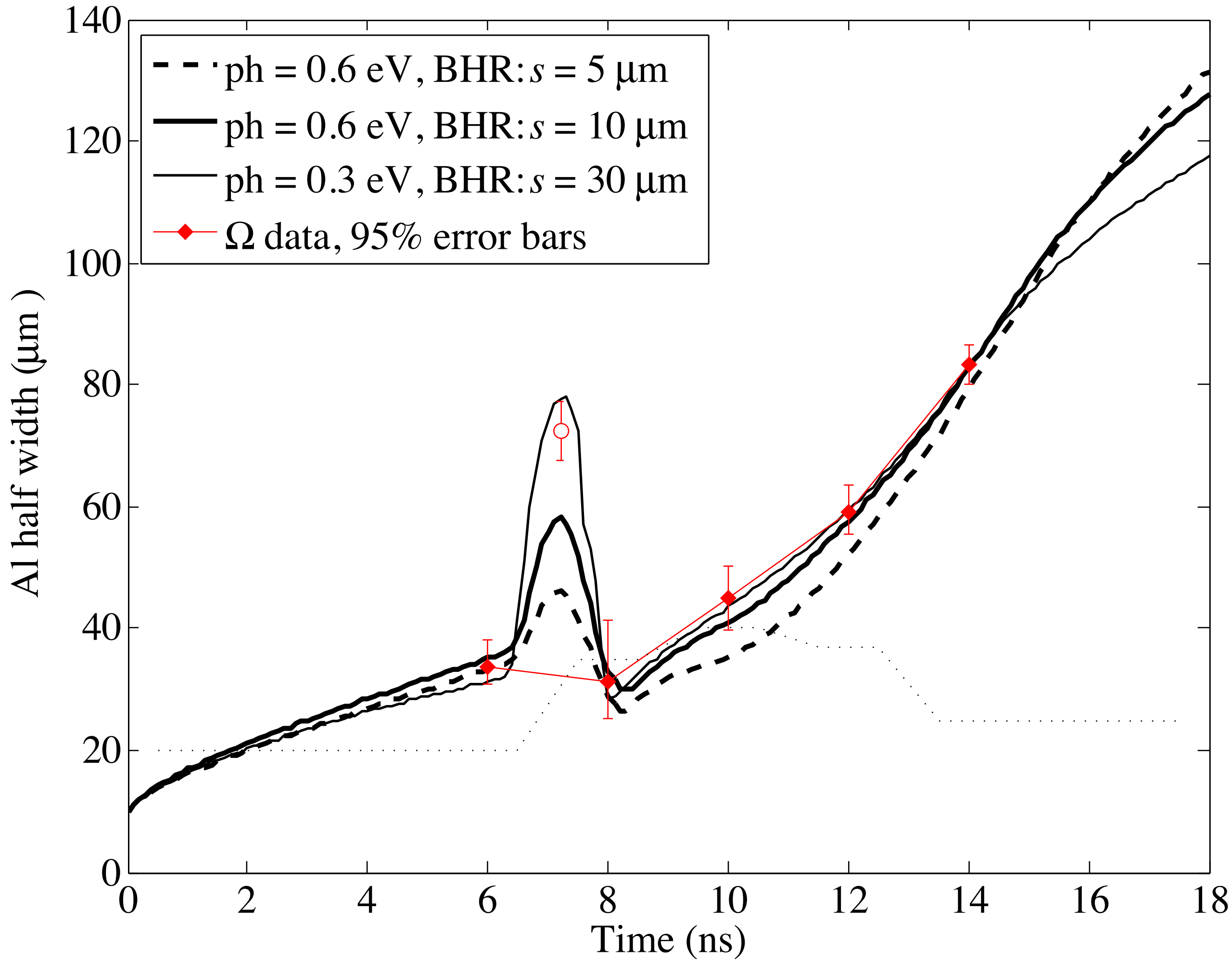
Conclusions

- RAGE calculations with BHR can match mix-width data generated in the counter-propagating shear experiment.
- The data is sensitive to the initial turbulent length scale parameter in BHR, the mix widths to a window of about 15 microns, the dust-up to a window of a few microns.
- The turbulent length scales which match the experiment are set by the initial width of the layer, rather than the initial roughness of the layer.
- Orthogonal radiography captures strong nonlinear evolution and transition to increasingly fine, diffuse structures.
- A NIF experiment with supported shocks could extend to later mixing times, longer shear regions, thicker plates, etc. and explore substantially more parameter space.

Extra slides

Simulations (especially dust-up) show sensitivity to the length scale *s*.

- **Other runs, compared to the data.**
- **10 – 30 microns can fit all standard points (excluding dust-up height).**



Energy deposition tuned for shock location

- Shock locations adequately predicted by simulation. Better job on the intact side.
- Energy tuned to get shock crossing time near experiment (6 ns sim location is between the two experimental times).
- Shocks not readily visible on 12 ns intact side (in process of bounce).